Chapter 5

Examples of Innovative Science Education Practices in the Future Classrooms

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Abstract

This book chapter addresses technology integration for innovative learning in future science classrooms. 21st-century science education aims not only for students to acquire conceptual knowledge, but also to develop higher-order skills such as scientific thinking, critical thinking, creativity, and digital literacy. The chapter examines the role and impact of technology-enhanced learning environments in science education. The applications of physical and digital tools in science education have been addressed through topics such as Arduino for experimental learning, 3D printers for modelling and production, laser cutting machines for precision prototyping and production, VEX IQ robotics kits for robotics and engineering implementations, PhET simulations for virtual experiences, Scratch for coding and modelling, Canva for visual communication, Kahoot! for formative assessment, and artificial intelligence for personalised learning experiences. Each technology is examined in terms of its contribution to learning experiences within the context of a student-centred learning perspective, and examples of classroom applications are provided. Consequently, future science classrooms will offer students the opportunity to experience scientific concepts in concrete contexts and develop 21st-century skills by integrating different technologies within a holistic ecosystem. The tools discussed in this study are examples, and the main point emphasised is the transformation that technologies create in learning processes. While organizations and individuals that effectively integrate technology gain an advantage, those unable to do so may remain at a disadvantage, and difficulties in accessing some technologies may further deepen existing technological and digital inequalities. Accordingly, infrastructure, financial support, and pedagogical guidance emerge as critical requirements.

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1. Introduction

21st-century science education aims to go beyond the mere transfer of knowledge and develop students' skills in scientific processes, conceptual understanding, critical thinking, creativity, and digital literacy (Dinçer, 2024; Voogt & Roblin, 2012). In this context, technology-enhanced learning environments (TEL) are one of the fundamental elements of transformation in science education. TEL enables students to participate more effectively in experiential, visual and simulation-based learning processes through the integration of physical and digital tools (Bower, 2017; Kirkwood & Price, 2014).

In recent years, digital transformation in education has led to an increase in interactive learning environments that encourage students to actively participate in design, production, and problem-solving processes, beyond simply learning abstract concepts (Organization for Economic Cooperation and Development [OECD], 2023; World Economic Forum [WEF], 2025). Innovative science education practices in the classrooms of the future encompass technologies such as prototyping and production tools, robotics and coding platforms, virtual simulations, visual communication tools, and artificial intelligence-supported applications. These applications make learning experiences more interactive and experiential, while also developing students' 21st-century skills such as scientific thinking, creativity, digital skills, and critical thinking (Future Classroom Lab (FCL) Türkiye, 2024; OECD, 2023).

These technologies support students' active participation in science education and also enhance teachers' opportunities to differentiate and personalise learning processes. The examples presented in continuing the section aim to contribute to the examination of various possibilities for science education practices in future classrooms. The physical and digital tools provided as examples have been determined based on innovative classroom practices implemented in an educational institution. In this way, efforts and experiences aimed at shaping the classrooms of the future can be shared, thus contributing to the planning and dissemination of innovative educational practices.

2. Arduino for Experimental Learning

Arduino is an important microcontroller platform that supports experimental and experiential learning in science and technology education with its open-source and modular design. Thanks to its low cost and accessibility, students can gain direct observation and data collection experience through physical computing applications (Arduino Education, n.d.; MIT Edgerton Center, n.d.). Arduino provides an interdisciplinary learning environment, enabling the integrated approach to science, technology, engineering, and mathematics concepts (García-Tudela & Marín-Marín, 2023). Applications created with Arduino kits encourage students to actively participate in problem-solving processes and support the development of algorithmic thinking and creativity skills (Sarı et al., 2022). Furthermore, Arduino applications enhance student-centred learning environments, thereby increasing students' interest in STEM subjects (Topcubasi & Tiryaki, 2023).

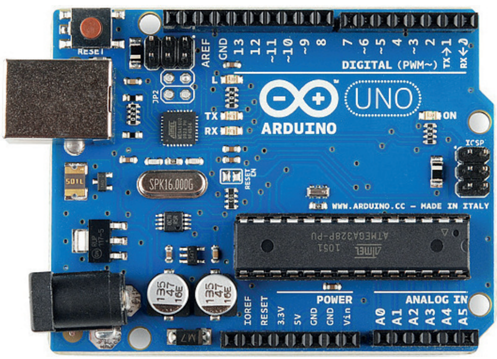

Figure 1. Arduino microcontroller

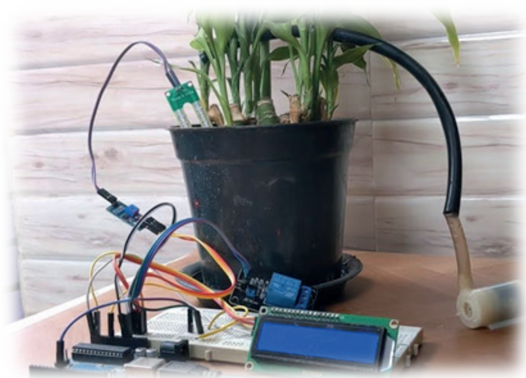

Figure 2. Plant watering system

In practice, Arduino is used as a development board that enables the control of sensors and devices by programming electronic circuits. In the developed automatic plant watering system, the soil moisture sensor measures the moisture level of the plant. When the moisture level is low, Arduino activates the water pump to automatically water the plant. Additionally, the moisture status can be monitored on the LCD screen. This enables students to explore science topics such as plants' water requirements, soil moisture, and the effect of water on plants using electronic circuits and sensors, in conjunction with the disciplines of physics, chemistry, biology, and mathematics.

3. 3D Printers for Modelling and Production

3D printing technologies are an innovative tool that enables the concretisation of abstract concepts. By taking an active role in the three-dimensional modelling process, students not only learn concepts but also develop production-based learning, problem-solving and design skills (Tejera et al., 2023). 3D printers support student-centred pedagogy in STEAM education; they encourage collaborative learning, creativity, and higher-order thinking skills (Ulbrich et al., 2024). Applications using 3D printers in science lessons directly support concept learning. For example, in biology teaching, three-dimensional modelling of cell organelles helps students eliminate misconceptions by examining cell structure in parts. In chemistry lessons, the 3D printing of molecular structures facilitates meaningful learning by visualising abstract types of bonding. In physics lessons, three-dimensional prototypes of force systems or simple machines develop students' experimental investigation and engineering design skills (Aslan et al., 2024).

Figure 3. 3D printer

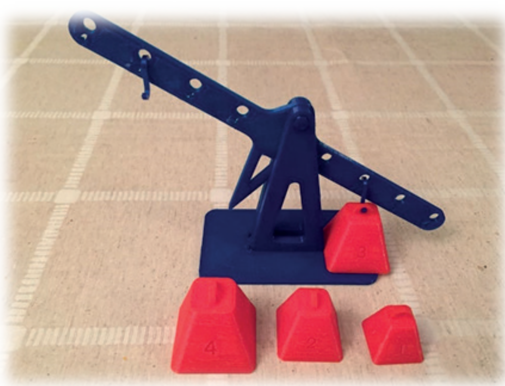

Figure 4. Lever principle

In practice, a 3D printer is used to transform a digital design, modelled in computer-aided design (CAD) software, into three-dimensional physical objects. The model demonstrating the lever principle allows students to experience the principle and concretize their understanding by visualising how different forces and lever arm lengths affect lifting.

4. Laser Cutting Machines for Precision Prototyping and Production

Laser cutting machines are an important tool for effectively implementing STEM-focused applications in education. Students use laser cutting technology to create, test and, when necessary, revise their designs, thereby developing their engineering problem-solving skills (Cai & Chiang, 2021). Similarly, laser cutting techniques have proven effective in fostering students' collaboration, design, and technology skills through project-based activities. This technology can be employed within experiential and problem-based learning processes (Jones et al., 2013). Laser cutters are new technologies preferred in educational production activities and support project-based learning (Lundberg & Rasmussen, 2018). Applications using laser cutters enhance students' creative design processes and consolidate their experience (Kamberg, 2017). Furthermore, these technologies play a significant role in the production of STEM-focused educational materials and in the development of technical and design skills (Bulut et al., 2025).

Figure 5. Laser cutting machine

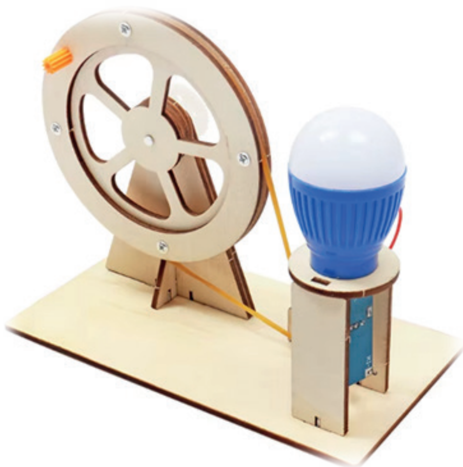

Figure 6. Hand crank generator

In practice, laser cutting machines are used to shape and cut wood and similar materials using a high-intensity laser beam based on digital drawings created in CAD software. This material converts mechanical energy into electrical energy. By observing the working principle of the generator, students can learn physical concepts such as electromagnetic induction and energy conversion through practical application.

5. VEX IQ Robotics Kits for Robotics and Engineering Implementations

VEX robotics kits are learning tools that enable student-centred, collaborative and experience-focused engineering design processes in science and STEM education. Through these kits, students develop their skills in technology, science, mathematics, and engineering by carrying out hands-on learning activities (VEX Education, n.d.). Furthermore, through the construction of robotic systems and sensor integration, students have the opportunity to develop their problem-solving skills as well as reinforce their technical knowledge. For example, VEX IQ-based applications increase student motivation and support the learning of science concepts in concrete contexts (Çalişkan, 2020). In addition, international events such as the VEX Robotics Competition contribute to students' development in advanced skills such as engineering design, strategic thinking, teamwork, and communication (Robotics Education & Competition [REC] Foundation, 2025).

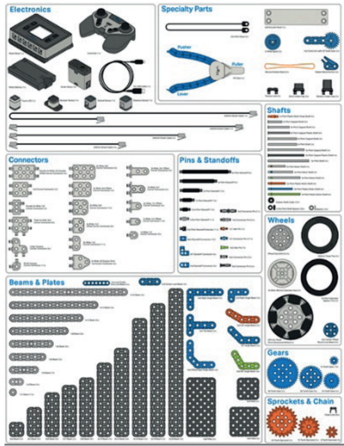

Figure 7. VEX IQ kit

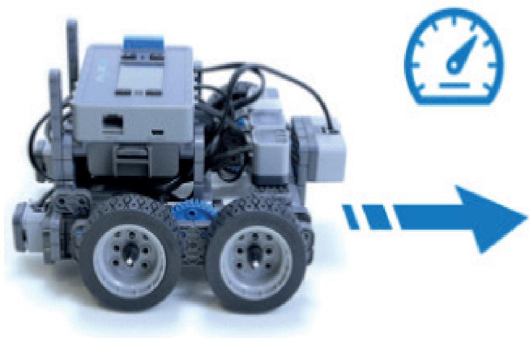

Figure 8. Changing velocity

In practice, VEX IQ is used as a platform and educational technology designed to develop science, robotics, and engineering implementations. With this technology, students can observe and experience physical quantities such as movement distance, duration, and acceleration by changing the robot's speed. This allows them to gain practical insight into fundamental physics concepts such as speed, acceleration, and the laws of motion.

6. PhET Simulations for Virtual Experiences

PhET (Physics Education Technology) simulations are powerful tools that enable students to experience abstract scientific concepts in a more concrete and interactive manner. Developed by the University of Colorado, these free and open-source simulations provide comprehensive teaching support in fields such as physics, chemistry, biology, and earth sciences (PhET, n.d.). PhET simulations are effective in increasing students' academic achievement and motivation. For example, one study found that students who learned with PhET simulations achieved higher results than those who used traditional teaching methods (Alsalhi et al., 2024). Furthermore, these simulations enable students to experience abstract concepts in a visual and interactive manner, thereby making the learning process more effective (Scott, 2025). Moreover, bibliometric analyses indicate that research on PhET simulations has increased in recent years and reveal significant trends in the literature toward enhancing students' conceptual understanding, supporting experiential learning, developing problem-solving and critical thinking skills, and increasing motivation (Harahap et al., 2025).

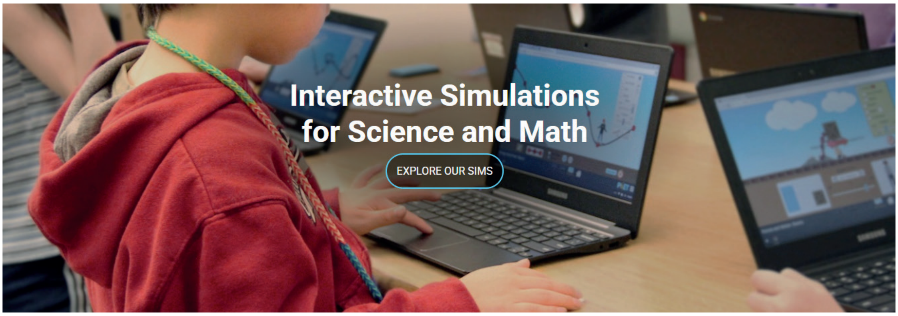

Figure 9. PhET simulations

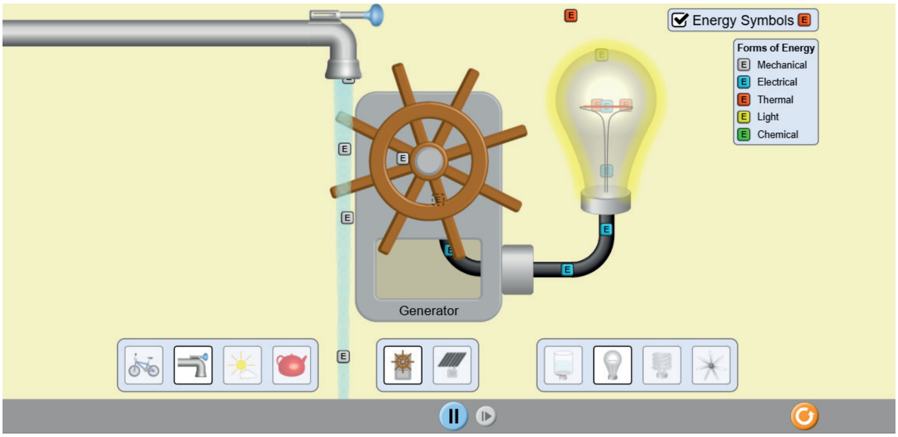

Figure 10. Energy forms and changes

PhET simulations are used in education to facilitate learning experiences through interaction and discovery. Students can conduct experiments and gain a deeper understanding of concepts. This simulation is an educational tool that allows students to explore types of energy and the transformations between them in a visual and interactive manner. It helps students understand fundamental physical concepts such as energy conversion and conservation through hands-on application.

7. Scratch for Coding and Modelling

Scratch is an effective tool for developing students' algorithmic thinking, problem-solving and creative design skills as a visual block-based programming language (Talan, 2020; Fagerlund et al., 2021). Scratch-supported activities play an important role in increasing students' interest in science and making their learning processes more interactive (Erol & Çırak, 2022). Furthermore, systematic reviews have also demonstrated that Scratch develops problem-solving skills and helps students better understand scientific concepts (Moreno-León & Robles, 2016). Scratch supports the modelling and solving of complex problems in science lessons, thereby contributing to the holistic development of students' skills in STEM subjects (Batni et al., 2025).

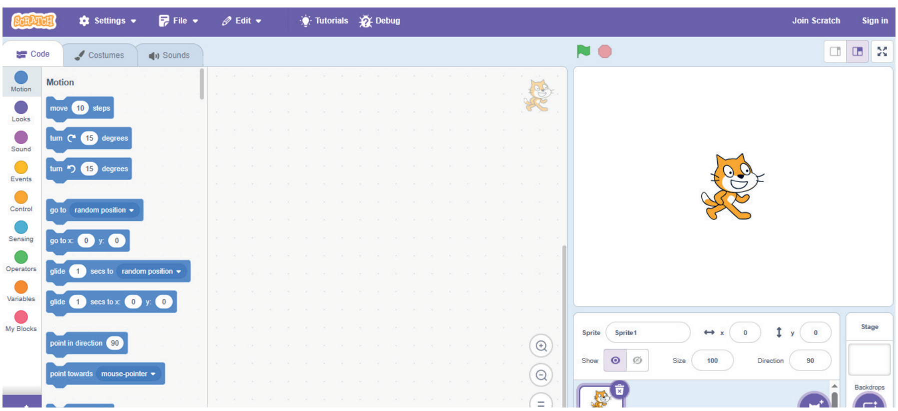

Figure 11. Scratch user interface

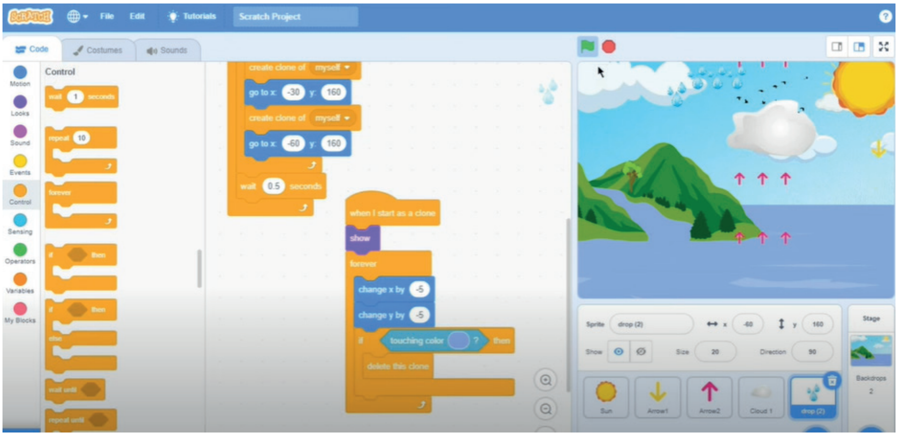

Figure 12. Water cycle simulator

In education, Scratch is used as a visual programming language that enables the design and sharing of animations, computer games, or interactive stories by combining various media elements such as images, sound, and music. This simulation enables students to learn about the water cycle interactively by visualising the processes such as evaporation, condensation, and precipitation.

8. Canva for Visual Communication

Visual communication is the process of conveying information and ideas through visual elements, and it makes the transfer of information more effective, particularly in education and the business world (Traboco et al., 2023). Canva, as an online platform that enables users to create professional visuals, is an important tool that enhances visual communication in education and professional life. It increases students' opportunities for creative expression and learning, and functions as an effective visual media platform in learning processes. Similarly, it enables teachers to make their teaching materials more effective and supports students' learning based on visual information (Rajendran et al., 2023). It has been observed that science learning videos created with Canva enable students to better understand socio-scientific topics and allow teachers to prepare teaching materials quickly and effectively (Jatmiko et al., 2024). Furthermore, Canva's visual and interactive features are an effective tool for making abstract scientific concepts concrete and enhancing students' science literacy (Warda et al., 2025). According to Canva's 2025 report, creative visual content can accelerate memory encoding by 74 percent (Robinson, 2025).

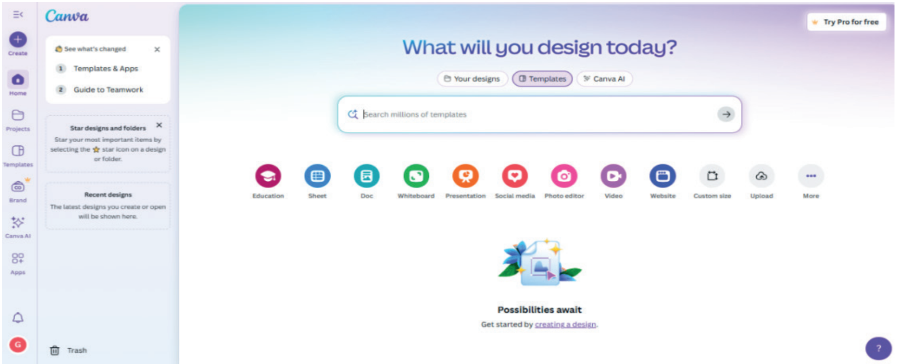

Figure 13. Canva user interface

Figure 14. Science template example

Canva is used in education as an online graphic design tool. It contains numerous templates for infographics, posters, banners, videos, etc. related to the relevant subject area and is available for users to utilise.

9. Kahoot! for Formative Assessment

Kahoot!, as an interactive and game-based learning platform, is effectively used as a formative assessment tool in science education. It has been determined that gamification-based student response systems are effective in science education, and that Kahoot, in particular, contributes significantly to developing conceptual understanding and learning retention among primary school pupils (Janković et al., 2024). It has been determined that the use of Kahoot! plays an important role in increasing the academic achievement, motivation, and participation of students in the physics teaching programme (Mdlalose et al., 2022). Similarly, Kahoot!, as a game-based formative assessment tool, increases student participation and satisfaction and contributes to making learning processes visible (Kalleny, 2020). Furthermore, a positive correlation has been established between the use of Kahoot! and students' academic achievements. These findings demonstrate that Kahoot! can be used as an effective formative assessment tool in educational processes (Koponen, 2025).

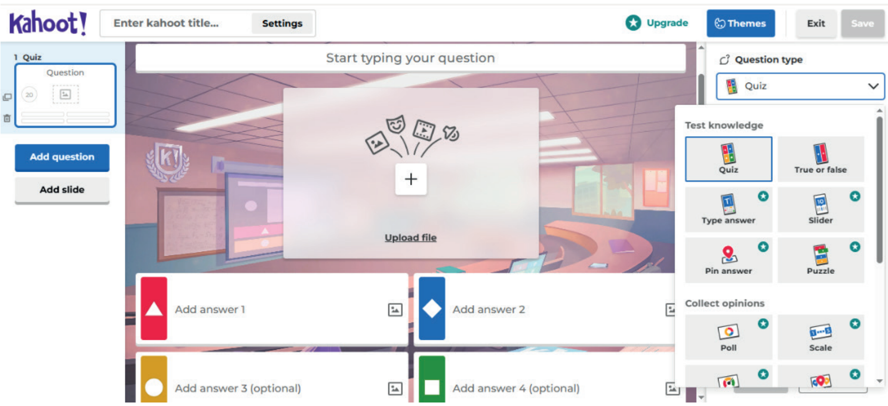

Figure 15. Kahoot! user interface

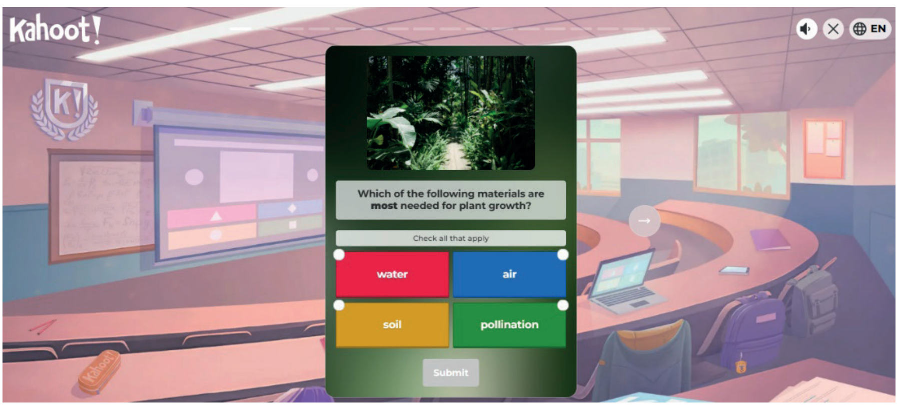

Figure 16. Kahoot science example

Kahoot! is used in education to facilitate learning through gamification, support teaching materials, reinforce students' learning, and conduct assessments. This quiz enables students to review and learn the essential elements required for plant growth. Students learn these concepts in an engaging and interactive manner through interactive questions.

10. Artificial Intelligence for Personalised Learning Experiences

Artificial intelligence (AI) is transforming learning experiences by delivering content tailored to students' individual needs and learning styles. AI-based systems can analyse student performance to provide personalised feedback and make learning processes more efficient (Ayeni et al., 2024). In educational settings, such applications increase student participation in lessons while facilitating the role of teachers and redefining the guidance function in teaching processes (Al Nabhani et al., 2025). Indeed, the integration of AI into classroom applications provides students with a more flexible and motivating learning environment by dynamically adapting learning materials (Jares, 2025). At every stage of science education, AI can be used as an effective tool to prevent misconceptions, meet individual learning needs, track performance, and provide immediate feedback (Yılmaz, 2023). Furthermore, AI-supported applications can support students' cognitive, emotional, and social development (Güven et al., 2025).

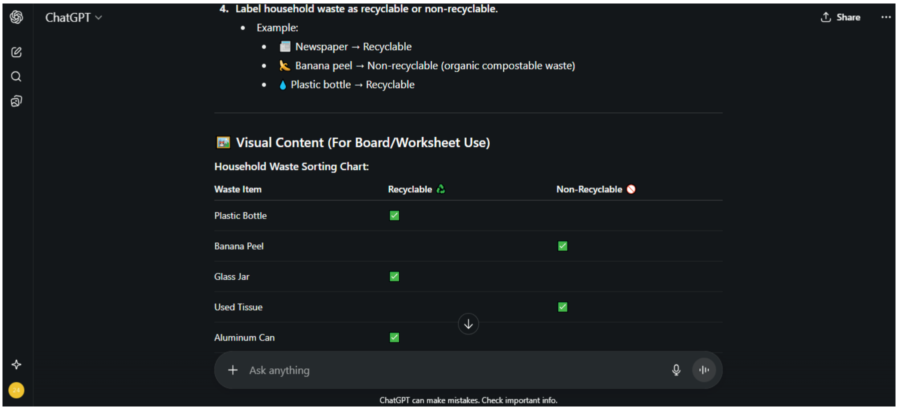

Figure 17. OpenAI ChatGPT interface - Learning outcomes-based science content example

ChatGPT can be used in education to develop science content focused on learning outcomes. It enables the design of activities and content tailored to learning objectives for students, making the teaching process more interactive and goal-oriented.

11. Conclusion, Future Perspectives and Recommendations

The science classrooms of the future require a comprehensive technology ecosystem that integrates experimental and experiential learning processes; design, prototyping, modelling, and production; simulation and visual communication; as well as gamification, assessment, and personalised learning approaches. The holistic use of these tools enables students to experience science concepts in concrete contexts by facilitating their active participation in design, prototyping, testing, and presentation processes through pedagogies such as problem-based learning, project-based learning, and design-based learning. It also supports the development of skills such as scientific thinking, critical thinking, problem solving, algorithmic thinking, creativity, and collaboration.

Future research could contribute to the more effective and widespread implementation of innovative science education practices by examining the impact of these tools on learning processes, models of interdisciplinary integration, and the sustainability of student-centred approaches. In this context, technology-enhanced science education is positioned as a flexible, interactive, and inclusive learning environment that develops students' 21st-century skills.

The physical and digital tools discussed in this study are presented merely as examples of some of the technologies that can be used in innovative science education environments. They can be integrated into science and STEM education programmes at various levels, from primary school to university. It should be borne in mind that different alternatives to the proposed tools may exist. Furthermore, various studies and application examples related to the technologies mentioned can be accessed through academic databases and online resources. The main emphasis here is on the growing interest in the relevant technologies and the transformation of learning and teaching processes through these technologies.

However, while institutions and individuals capable of integrating these technologies into educational activities are at an advantage in terms of imparting and experiencing 21st-century skills, those unable to achieve integration may find themselves at a disadvantage. Furthermore, difficulties in accessing some technologies may further deepen existing technological and digital inequalities. Therefore, despite integration and access issues, it is important that relevant institutions or individuals develop projects with an innovative approach and that funding is available for these projects. In this regard, the effective use of these learning environments should be supported by providing educational institutions with technological infrastructure and pedagogical guidance.

Note: The work of the relevant educational institution has not been included directly due to its potential intellectual property status and the possibility of containing personal data; examples are presented solely within the context of the topic.

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